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Probabilistic Evaluation of Turbine Valve Test Frequency

Westinghouse Electric Company LLC

WCAP-15786

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Mitsubishi Heavy Industries, Ltd.

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1 EXECUTIVE SUMMARY

The purpose of this report is to provide the detailed probabilistic basis for the valve test interval. The annual probability of turbine missile ejection has been calculated using detailed nuclear turbine operating data. Testing of turbine valves affects the probability that the valves will be incapable of closing given that the load on the turbine is lost. The failure or unavailability of the turbine valve safety function affects or contributes to the probability that the turbine will overspeed and eject a missile.

Turbine missiles can be ejected at overspeeds that are less than the destructive or runaway speed of the turbine. The current study has attempted to quantify the total risk of turbine missile ejection at destructive overspeed (Approximately [ ]^{b,c} percent of rated turbine speed) and at lower overspeeds. The lower overspeeds were evaluated in two categories: design overspeed and intermediate overspeed. The total missile ejection risk is developed in this report as the sum of the missile ejection probabilities from each of the three overspeed categories. Section 5 of this report discusses the basis for the analysis of turbine overspeed.

Significant changes have occurred in the design of low pressure rotors and rotor discs in recent years. The general trend has been toward designs that reduce or eliminate the problem of disc stress corrosion cracking. This, in turn has resulted in significant reductions in the probability of missile ejection at design overspeed. This should have the effect of further reducing in the probability of missile ejection at design and intermediate overspeed, and these overspeed events will contribute even less to the total probability of turbine missile ejection.

Section 6 of this report contains the detailed results of the probabilistic investigation. Figure 6-1 shows the total probability of turbine missile ejection as a function of the turbine valve test interval. Test intervals of one month to twelve months were considered in the study.

Evaluation showed that the probability of turbine missile generation with quarterly valve test is less than the evaluation criteria.

2 INTRODUCTION

In recognition of the effects of turbine valve testing on the probability of low pressure turbine missile ejection, Mitsubishi Heavy Ind. Ltd. evaluated the need for periodic valve testing and to establish appropriate test intervals. This report contains the results of that evaluation.

The evaluation performed consisted of estimation of component failure rate and the annual probability missile ejection. Failures of turbine valves and overspeed protection components were evaluated on the basis of Japanese nuclear steam turbine operating experiences. The annual probability of missile ejection was calculated for various test intervals.

3 TURBINE VALVE TESTING AND IMPACT

Testing is conducted to verify that equipment is capable of performing its intended function. The turbine valves function to control and protect the main turbine. They must be capable of moving freely in response to control and protection signals. Valve testing ideally tests these abilities or detects non-performance of these abilities. There are two degrees of performance or non-performance that testing may potentially demonstrate:

1. Equipment failure – the complete non-performance of equipment function.

2. Equipment failure precursors – identification of equipment conditions that will eventually lead to failure if not corrected.

A test which only identifies equipment failure is useful in limiting the time after failure that the faulty equipment may be relied on. A test which identifies failure precursors can impact the time between and the number of failures if the precursors are acted on. This section of the report addresses turbine valve testing and its implications on valve failure rate.

3.1 TURBINE VALVE TESTING

Periodic testing of turbine valves consists of movement of each of the turbine valves through one cycle (from the valve position prior to testing, to full close, and returning to the original position). Typically, this test is conducted by the control room operator with an observer at the valve. Valve testing verifies freedom of movement of the valve stem and plug, the actuator rod and piston and verifies proper operation of either the servo valve, servo, motor, or dump valve, depending on which valve is being tested, and the associated drain line (return line) to the reservoir. Testing verifies closure of the turbine valves as testing is now constituted, i.e., nothing is inhibiting closure. This type of testing is beneficial for, (1) detecting non or sluggish operation of the valves, and (2) identification of gross outward appearance of valve condition.

In addition to periodic testing, valve inspections during a shutdown can detect distress or conditions that would lead to future valve failure. In the current study, the valve inspection interval was not an input parameter. However, actual service experience has been used in the calculation of valve failure rates (Section 6). These failure rates reflect the average practice of the nuclear industry with respect to inspection and maintenance of turbine valves.

3.2 SURROGATE VALVE TESTING

Periodic valve testing primarily demonstrates the ability of the valve to respond to a signal and close upon demand. Both planned and unplanned turbine trips can also demonstrate these abilities and can be considered surrogate valve tests for which a valve test "credit" can be taken. All turbine trips result in the dumping of autostop oil and the operation of systems which dump high pressure oil or electrohydraulic fluid from the turbine valve actuators.

For planned trips, plant operators observe the valves to visually check valve operation during the trip qualifies as a surrogate valve test provided there has been no evidence of malfunction of control or governor valves during normal operation. For unplanned trips, the only significant difference from a planned trip or a typical valve test is the absence of an observer at the valves. In this case, sufficient evidence of proper valve operation can be obtained if an operator looks at each turbine valve not too long after the trip and verifies that all valves are in the closed position and that conditions with respect to the valves appear normal.

This operator activity would then qualify as a surrogate valve test.

3.3 VALVE FAILURE MODES AND IMPACT OF TESTING

The dominant occurrence of valve failure modes, such as sticking and mechanical damage, can be attributed to the following:

1. Movement or loss of valve internal components
2. Cracking or breaking of the muffler
3. Piston seal ring-bonnet, bushing, or liner galling or distress
4. Misalignment of valve linkage

These conditions are primarily internal to the valves, and periodic testing would identify these conditions only to the extent that they are apparent to an observer or that they prevent valve operation. Periodic testing most often identifies failures. Failure precursors that do not noticeably affect the rate of closure or final position of a valve are not easily detected in testing. For example, a cracked muffler could potentially result in later muffler failure and subsequent internal valve binding; however, the "precursor" could not be detected during testing, only the subsequent failure of the valve could be detected.

For the above reasons, periodic valve testing does not have an impact on valve failure rate for these types of valves in that it has not readily identified failure precursors, only failures. Therefore, increasing the periodic test interval will have no adverse impact on observed failure rates or valve lifetime. Testing that does not identify repairable defects cannot influence valve degradation and therefore valve failure rate.

Based on the above discussion, it can be concluded that valve test frequency will not impact turbine valve failure rate.

4 DESCRIPTIONS OF TURBINE VALVES AND OVERSPEED CONTROLS

The following sections describe the turbine valves and its control system. The turbine valve arrangement for AP1000 is shown in Figure 5-1, and turbine control oil system is shown in Appendix A.

4.1 TURBINE VALVES

Main stop valves and governing valves, and interceptor and reheat stop valves are located in the steam lines to the high and low pressure turbines, respectively.

Main stop (throttle) valves close automatically in response to the dumping of emergency trip oil (MSV & RSV) which will occur in an overspeed trip or a system separation. The controls and trips that dump emergency trip oil are discussed in Section 4.2. In normal operation, each main stop (throttle) valve is held open against a closing spring force by high pressure oil acting on the servo-actuator piston. Each main stop (throttle) valve has a dump valve that opens if the emergency trip oil (MSV & RSV) pressure is dumped. This in turn, routes the high pressure oil to drain and the main stop valve, equipped with large closing springs, closes rapidly.

Governing (control) valves adjust the inflow of steam to the turbine in response to the speed or load demand placed on the turbine-generator. Each has a servo valve and a dump valve. The servo valve receives an electrical input from the electronic controller and positions the steam valve through the control of high pressure oil to the servo-actuator. The electronic controller is a digital processor receiving turbine speed and first stage pressure inputs. The governing (control) valve will move rapidly to the fully-closed position if the dump valve is opened by a trip or protective device that dumps the emergency trip oil (GV & ICV). Various controls and trips, discussed in Section 4.2, are designed to dump the emergency trip oil (GV & ICV) on loss of load or overspeed.

Interceptor and reheat stop valves are held open by high pressure oil operating on the pistons of the servo-actuators. Each interceptor valve has a dump valve that is connected to a emergency trip oil (GV & ICV) header.

The dump valves will open in response to a dump of the emergency trip oil and close the interceptor valves. Reheat stop valves have dump valves that are connected to the emergency trip oil (MSV & RSV) header.

Reheat stop valves will close in response to a dump of the emergency trip oil (MSV & RSV).

4.2 TURBINE CONTROL AND OVERSPEED PROTECTION

The DEH control system controls the flow of steam to the turbine and permits the selection of the desired turbine speed and acceleration rates. The primary speed channel and turbine impulse stage pressure are the primary inputs to the valve electronic controller, which positions the governing (control) valves. If the turbine accelerates from its normal speed, the primary speed channel and servo valve on each governing valve will rapidly reduce the oil pressure acting on the governing valve servo-actuators. This causes the governing valves to close until the turbine returns to normal speed.

Three additional overspeed protection controls are available to prevent overspeed.

First, the overspeed protection controller will activate with loss of load or at an overspeed setpoint depending on load unbalance and automatically open solenoid valves that will drain the emergency trip oil (GV & ICV) and cause the governing valves and interceptor valves to close.

Second, a mechanical overspeed trip valve, consisting of an eccentric weight, trigger, and cup valve, will activate at an overspeed setpoint that does not exceed 110+0.5, 110-0.5 percent, and drain the autostop oil. This releases pressure on the diaphragm of the emergency trip valve (interface diaphragm valve) which then opens and drains the emergency trip oils.

Third, an electrical overspeed trip mechanism consisting of a diaphragm and turbine trip solenoid valve will activate with system separation due to a generator trip signal. The turbine trip emergency valve drains the emergency trip oil for the GVs & ICVs and the emergency trip oil for the MSVs & RSVs, which causes the turbine valves to close. The solenoid valve is also activated by an overspeed signal of approximately 111 percent.

In the event of a turbine trip prior to a generator trip, the opening of generator output breakers is delayed for [ ][b,c] seconds following the turbine trip. During this period, the turbine is allowed to motor; and turbine speed is governed by grid frequency. The delayed generator trip usually results in negligible overspeed.

5 BASIS FOR ANALYSIS

5.1 TURBINE VALVE ARRANGEMENT AND CONTROL OIL SYSTEM

Figure 5-1 describes the turbine valving on the steam inflow lines to the high pressure turbine and the low pressure turbine.

The steam turbine for AP1000 plant in the study has the DEH system. Appendix A shows the applicable control oil system drawing.

The trip components were described in Section 4 of this report. Control oil system for AP1000 steam turbine has a mechanical overspeed trip device and a cup valve which dump the autostop oil in a manner to close all the steam valves including MSV, GV, RSV and ICV. The dump of autostop oil causes an emergency trip valve (interface diaphragm valve) to open, which dumps the emergency trip oil for the MSVs & RSVs and emergency trip oil for the GVs & ICVs.

This system also includes two sets of overspeed protection control solenoid valves, either of which will dump the emergency trip oil for the GVs & ICVs.

5.2 IDENTIFICATION OF OVERSPEED EVENTS

Before discussing the type of overspeed events that are of concern in this study, it should be pointed out that turbine overspeed is sometimes planned for the purpose of testing overspeed trip mechanisms. The test conditions are controlled so that the turbine speed reaches, but does not greatly exceed the overspeed trip setpoint of the turbine. This setpoint is in the range of [ ][b,c] percent of rated speed. The risk of missile ejection at these low overspeeds is small and was not evaluated in this study. The current study focuses on overspeed events that occur inadvertently following a system separation or loss of load. These events generally involve system failure sequences causing overspeeds that approach or exceed the design overspeed of the turbine.

"Design overspeed," "Intermediate overspeed" and "Destructive overspeed" were taken into consideration in this study.

The "Design overspeed" event is one in which the maximum speed of the turbine approaches but does not exceed an overspeed of 120 percent of rated speed. "Design overspeed" will be approached if the overspeed protection controller or the governing valves or interceptor valves fail to function and the main stop and reheat stop valves close after turbine speed reaches the overspeed trip setpoint.

The following is description of the basis for "Design overspeed":

1. System separation occurs

2. One or more governing (control) valves, or two or more interceptor valves, fail to close immediately following loss of load

3. Successful overspeed trip: the main stop (or throttle) valves and reheat stop valves close

"Intermediate overspeed" has been estimated to be approximately 10 percent above design overspeed. Generally, intermediate overspeed involves a failure to block to the low pressure turbine. The failure of the reheat stop and interceptor valves to close at the overspeed trip setpoint results in a transfer of energy to the low pressure turbine for a longer duration than what occurs in design overspeed.

The following is a description of the basis for "Intermediate overspeed" for the turbine:

1. System separation occurs
2. One or more alignments of RSV/ICV remain open

"Destructive overspeed" results from failure of one or more main stop (throttle) valves to close and failure of one or more governing valves downstream of the failed main stop valve (in the same steam chest). Destructive overspeed is on the order of [ ]^{b,c} percent of rated speed. Failure of RSV or ICV has no impact on this event. The following is an abbreviated description of the basis for "Destructive overspeed":

1. System separation occurs

2. One or more governing (control) valves fail to close

3. One or more main stop (throttle) valves, in the same steam chest as the failed governing valve, fail to close

5.3 BASIS FOR CALCULATION OF MISSILE, EJECTION PROBABILITIES

The regular testing of turbine valves and the regular inspection of the low pressure turbine rotors are two effective ways of controlling and managing the risk of turbine missile ejection. The main goal of this study was to determine the probability of turbine missile ejection and the effect of the turbine valve test interval on this probability. Turbine valve testing affects only the probability of missile ejection resulting from overspeed of the turbine. Therefore, this study concentrated on missile ejection from overspeed.

Before discussing the basis for calculating the probability of missile ejection due to overspeed, it should be mentioned that all of the plants have a program of low pressure rotor inspection. In the deterministic program, the LP rotors are inspected and the time that it takes for a hypothetical crack in the rotor to grow to critical size (the crack size that is just large enough to result in rotor failure) is calculated. If the inspection indicates the presence of cracks, the inspection time is further reduced. Half of this time is generally used as a deterministic basis for establishing the length of time before the next rotor inspection. This program effectively assures that the risk of missile ejection at running speed is very small because a very conservative criterion is used to establish the time interval to the next inspection.

The effect of varying the turbine valve test interval was evaluated by calculating the total probability of turbine missile ejection, P, for the three identified overspeed events. The formula used to calculate P is reproduced in Table 5-1 and is discussed in the following paragraphs.

The probability of missile ejection due to design overspeed is the product of the probability of design overspeed, P(A), and the conditional probability of missile ejection at design overspeed, P(M/A). In words, P(M/A) is the probability of ejecting a missile given that the turbine reaches design overspeed. A product of P(B) and P(M/B) results in the probability of missile ejection for the intermediate overspeed event. P(C) by itself denotes the probability of missile ejection for the destructive overspeed event because the conditional probability, P(M/C), is assumed to be one in the study.

P(M/A) was obtained from probabilistic reports on missile ejection from fully integral low pressure turbine rotors (WCAP-15783, April 2002, "Analysis of the Probability of the Generation of Missiles from Fully Integral Nuclear Low Pressure Turbines"). It involves a calculation of the probability of failure of low pressure turbine rotor based on Mitsubishi Heavy Ind. Ltd. crack growth data, the stress generated at design overspeed, and the resultant critical crack size.

The probability of low pressure turbine rotor failure is broken into two parts: the probability that a crack initiates and the probability that the crack has grown beyond critical size after a certain interval of time.

Section 4 of WCAP-15783, April 2002, "Analysis of the Probability of the Generation of Missiles from Fully Integral Nuclear Low Pressure Turbines" shows the probability of missile ejection depending on inspection interval and concludes that the probability of missile ejection for full integral rotor with low yield strength is extremely low when the rotor rotating speed is suppressed under "Design overspeed" or "Intermediate overspeed."

Based on the above discussion, it can be concluded that probability of P(A)*P(M/A) and P(B)*P(M/B) is negligibly small compared to P(C) in case of full integral rotor with low yield strength, which will be applied to AP1000 low pressure turbine rotor.

Section 6 of this report gives the detailed results of the evaluation of P for the various turbine valve test intervals.

5.4 ASSUMPTIONS (BASIS FOR ANALYSIS)

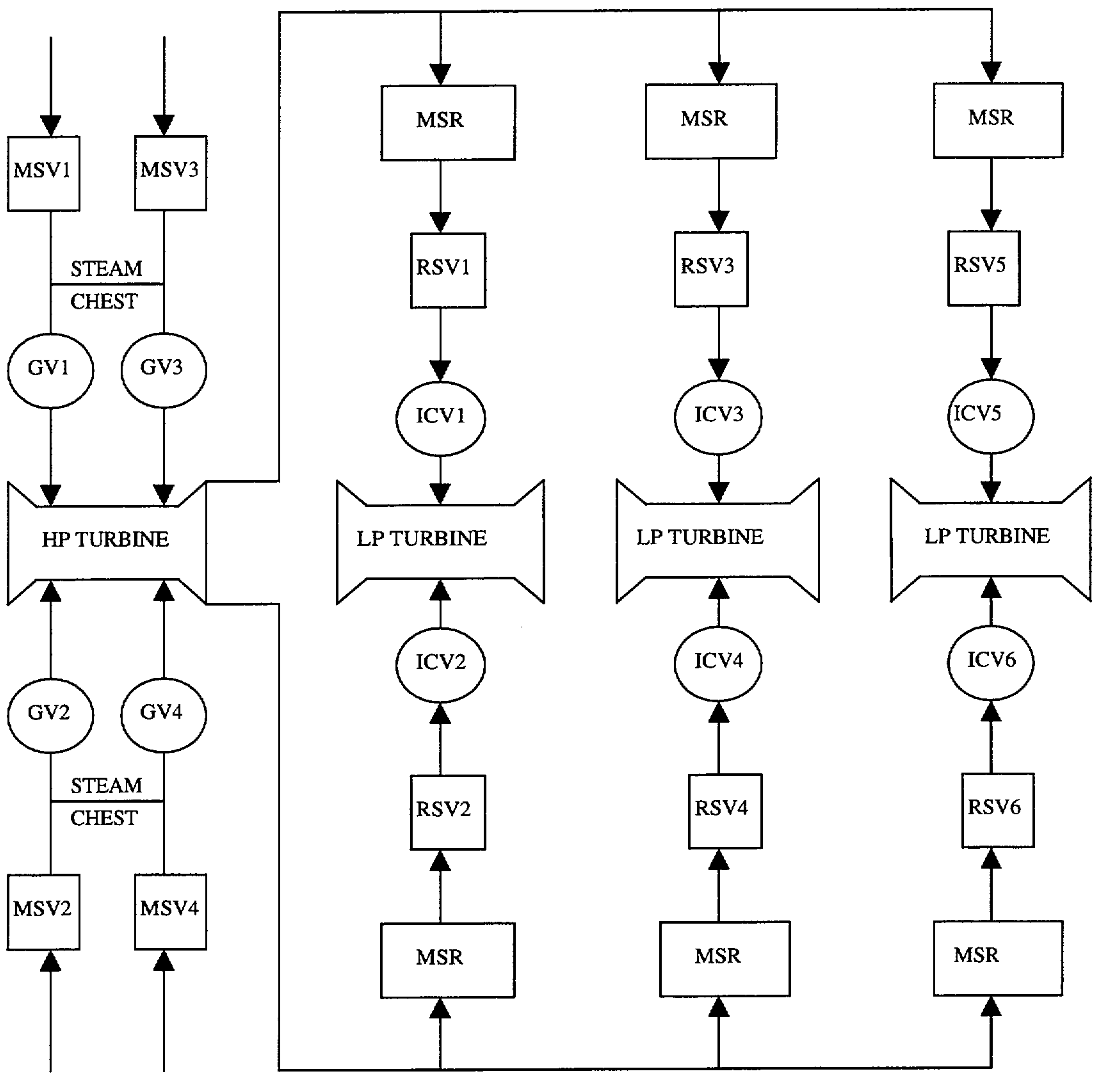
The assumptions below pertain to the basis for analysis:

- A failure sequence consisting of a failure of a control valve and reheat stop/interceptor valve combination along with a failed-open stop valve bypass valve has not been analyzed because the probability of failure of four dissimilar valves is assumed to be very small.

- The design overspeed events are assumed to result in 120 percent overspeed even though it is likely that the actual overspeed would be less. This gives additional conservatism to the analysis.

- P(A)*P(M/A) and P(B)*P(M/B) is negligibly small compared to P(C) and these probabilities can be regarded as zero (0).

Table 5-1	**Basis for Calculation of P (Resulting From Turbine Overspeed)**
	P = P(A)* P(M/A) + P(B)* P(M/B) + P(C)
Where:	
P	Annual probability of turbine missile ejection
P(A)	Annual probability of design overspeed
P(B)	Annual probability of intermediate overspeed
P(C)	Annual probability of destructive overspeed
P(M/A)	Conditional probability of missile ejection at design overspeed
P(M/B)	Conditional probability of missile ejection at intermediate overspeed



Legend

MSV	:	Main Stop Valve
GV	:	Governing Valve
RSV	:	Reheat Stop Valve
ICV	:	Interceptor Valve
MSR	:	Moisture Separation Reheater

Figure 5-1 Arrangement of Turbine Valves

6 FAILURE DATA AND ANALYSIS OF BASIC FAILURE PROBABILITY

6.1 SOURCES OF FAILURE DATA AND METHOD OF ANALYSIS

The primary source of basic failure data in this study was from the operating experiences of Mitsubishi Heavy Ind. Ltd. nuclear steam turbines. A total of 23 nuclear units data was used for this study.

The basic service experience data and years of service, is given in Table 6-1 and Table 6-2.

6.2 DETERMINATION OF FAILURE RATE OF EACH COMPONENT

Failure rates of each component including main stop valve (MSV), MSV control system, governing valve (GV) and GV control system were obtained based on the following equation and calculated results with 95% confidence are shown in Table 6-3.

Failure Rate	:	$\lambda(\alpha)/2$
$\lambda(\alpha)$	:	$X^2(\phi,1-\alpha)/T$
X^2	:	Chi square distribution
T	:	Accumulated operating hours
ϕ	:	Degree of freedom = $2f + 2$
f	:	Number of observed failures

6.3 DETERMINATION OF ANNUAL PROBABILITY OF TURBINE MISSILE EJECTION

According to the discussion in Section 5 in this study, probability of turbine missile ejection for AP1000 was determined by the following equations.

Table 6-4 and Figure 6-1 demonstrate the calculated results showing the relationship between annual probability of turbine missile ejection and time interval of valve tests.

System Separation Rate, Q_{SS}, is evaluated based on 23 Japanese PWR nuclear plant experiences. Tables 6.1 and 6.2 show the number of system separations that occurred during turbine on-load conditions and the accumulated operating hours of the 23 PWR units. These data lead to the conclusion that the probability of system separation during operation is [ ][b,c]. In order to make the evaluation conservative, ten (10) times the probability of system separation above, [ ][b,c], is adopted in this evaluation.

$$P = N*2*(Q_{SV} + Q_{SC})*(Q_{GV} + Q_{GC})*Q_{SS}$$

P	:	Probability of turbine missile ejection	1/Time Interval
Q_{SV}	:	Failure Probability of MSV = $q_{SV}/2n$	1/Time Interval
Q_{SC}	:	Failure Probability of MSV control system = $q_{SC}/2n$	1/Time Interval
Q_{GV}	:	Failure Probability of GV = $q_{GV}/2n$	1/Time Interval
Q_{GC}	:	Failure Probability of GV control system = $q_{GC}/2n$	1/Time Interval

Q_{SS}	:	System Separation Probability	1/Time Interval
N	:	Number of main steam pipes	-
n	:	Number of valve tests per month	-
q_{SV}	:	Failure rate of MSV per month	per month
q_{SC}	:	Failure rate of MSV control system per month	per month
q_{GV}	:	Failure rate of GV per month	per month
q_{GC}	:	Failure rate of GV control system per month	per month

Where, "Time Interval" denotes "Time Interval between Valve Tests"

Table 6-1 Basic Service Experience Data in Japanese Nuclear Power Stations

	Unit Name	MSV Fault	GV fault	MSV Control System Fault	GV Control System Fault	System Separation
1	TSURUGA NO. 2					
2	TOMARI NO. 1					
3	TOMARI NO. 2					
4	MIHAMA NO. 1					
5	MIHAMA NO. 2					
6	MIHAMA NO. 3					
7	TAKAHAMA NO. 1					
8	TAKAHAMA NO. 2					
9	TAKAHAMA NO. 3					
10	TAKAHAMA NO. 4					
11	OHI NO. 1					
12	OHI NO. 2					
13	OHI NO. 3					
14	OHI NO. 4					
15	IKATA NO. 1					
16	IKATA NO. 2					
17	IKATA NO. 3					
18	GENKAI NO. 1					
19	GENKAI NO. 2					
20	GENKAI NO. 3					
21	GENKAI NO. 4					
22	SENDAI NO. 1					
23	SENDAI NO. 2					
TOTAL (As of March 2002)						

b,c

Table 6-2 Years of Service for Unit and Component in Japanese Nuclear Power Stations

	Unit Name	Output (MW)	Commercial Operation (-)	Accumulated Operating Hours of Unit (Note 1,2) (hr)	Number of MSV (-)	Number of GV (-)	MSV Component Accumulated Operating Hours (hr)	GV Component Accumulated Operating Hours (hr) b,c
1	TSURUGA NO. 2							
2	TOMARI NO. 1							
3	TOMARI NO. 2							
4	MIHAMA NO. 1							
5	MIHAMA NO. 2							
6	MIHAMA NO. 3							
7	TAKAHAMA NO. 1							
8	TAKAHAMA NO. 2							
9	TAKAHAMA NO. 3							
10	TAKAHAMA NO. 4							
11	OHI NO. 1							
12	OHI NO. 2							
13	OHI NO. 3							
14	OHI NO. 4							
15	IKATA NO. 1							
16	IKATA NO. 2							
17	IKATA NO. 3							
18	GENKAI NO. 1							
19	GENKAI NO. 2							
20	GENKAI NO. 3							
21	GENKAI NO. 4							
22	SENDAI NO. 1							
23	SENDAI NO. 2							
TOTAL								

Note-1: Accumulated Operating Hours of Unit includes trial operation hours

Note-2: Accumulated Operating Hours of Unit as of 2002.2.1

Table 6-3 Failure Rate of Each Components (95% Confidence)

Component	T: Accumulated Operating Hours (hr)	f: Number of Failures (-)	Failure Rate	
			Mean (-/hr)	Upper Limit (95% Confidence) (-/hr)
MSV				
MSV Control System				
GV				
GV Control System				
System Separation				

b,c

Note: Failure Rate derived based on following equation

Failure Rate (Mean) = f (Number of Failure)/T (Accumulated Operating Hours)

Failure Rate (Upper Limit)

	Unit	MSV	MSV Control System	GV	GV Control System	System Separation
F: Number of Failure						
ϕ: Degree of Freedom = 2f+2						
$X^2(\phi,1-\alpha)$						
T: Accumulated Operating Hours						
$\lambda(\alpha) = X^2(\phi,1-\alpha)/T$						
Failure Rate (Upper Limit) = $\lambda(\alpha)/2$						

b,c

Table 6-4 Annual Probability of Turbine Missile Ejection (95% Confidence)

Time Interval Between Turbine Valve Tests = 1 (Month)							
		Unit	**MSV**	**MSV Control**	**GV**	**GV Control**	b,c
Failure Rate (Upper Limit)	q	per Hour					
		per Month					
Frequency of Valve Test	n	per Month					
Time Interval of Valve Test		Month					
Probability of Failure	Q=q/2n	1/(Time Interval)					
	$(Q_{SV}+Q_{SC})$ or $(Q_{GV}+Q_{GC})$	1/(Time Interval)					
Probability of System Separation	Q_{SS}	per hour					
		1/(Time Interval)					
Probability of Turbine Missile	P	1/(Time Interval)					
		per Year					
Time Interval Between Turbine Valve Tests = 2 (Month)							
		Unit	**MSV**	**MSV Control**	**GV**	**GV Control**	b,c
Failure Rate (Upper Limit)	q	per Hour					
		per Month					
Frequency of Valve Test	n	per Month					
Time Interval of Valve Test		Month					
Probability of Failure	Q=q/2n	1/(Time Interval)					
	$(Q_{SV}+Q_{SC})$ or $(Q_{GV}+Q_{GC})$	1/(Time Interval)					
Probability of System Separation	Q_{SS}	per hour					
		1/(Time Interval)					
Probability of Turbine Missile	P	1/(Time Interval)					
		per Year					
Time Interval Between Turbine Valve Tests = 3 (Month)							
		Unit	**MSV**	**MSV Control**	**GV**	**GV Control**	b,c
Failure Rate (Upper Limit)	q	per Hour					
		per Month					
Frequency of Valve Test	n	per Month					
Time Interval of Valve Test		Month					
Probability of Failure	Q=q/2n	1/(Time Interval)					
	$(Q_{SV}+Q_{SC})$ or $(Q_{GV}+Q_{GC})$	1/(Time Interval)					
Probability of System Separation	Q_{SS}	per hour					
		1/(Time Interval)					
Probability of Turbine Missile	P	1/(Time Interval)					
		per Year					

Table 6-4 Annual Probability of Turbine Missile Ejection (95% Confidence) (cont.)

Time Interval Between Turbine Valve Tests = 6 (Month)

b,c

		Unit	MSV	MSV Control	GV	GV Control
Failure Rate (Upper Limit)	q	per Hour				
		per Month				
Frequency of Valve Test	n	per Month				
Time Interval of Valve Test		Month				
Probability of Failure	Q=q/2n	1/(Time Interval)				
	$(Q_{SV}+Q_{SC})$ or $(Q_{GV}+Q_{GC})$	1/(Time Interval)				
Probability of System Separation	Q_{SS}	per hour				
		1/(Time Interval)				
Probability of Turbine Missile	P	1/(Time Interval)				
		per Year				

Time Interval Between Turbine Valve Tests = 12 (Month)

b,c

		Unit	MSV	MSV Control	GV	GV Control
Failure Rate (Upper Limit)	q	per Hour				
		per Month				
Frequency of Valve Test	n	per Month				
Time Interval of Valve Test		Month				
Probability of Failure	Q=q/2n	1/(Time Interval)				
	$(Q_{SV}+Q_{SC})$ or $(Q_{GV}+Q_{GC})$	1/(Time Interval)				
Probability of System Separation	Q_{SS}	per hour				
		1/(Time Interval)				
Probability of Turbine Missile	P	1/(Time Interval)				
		per Year				

b,c

Figure 6-1 Annual Probability of Turbine Missile Ejection (95% Confidence)

APPENDIX A
CONTROL OIL DIAGRAMS

b,c

b,c

b,c

b,c